



## MURI 2001 Review

# Experimental Study of EMP Upset Mechanisms in Analog and Digital Circuits

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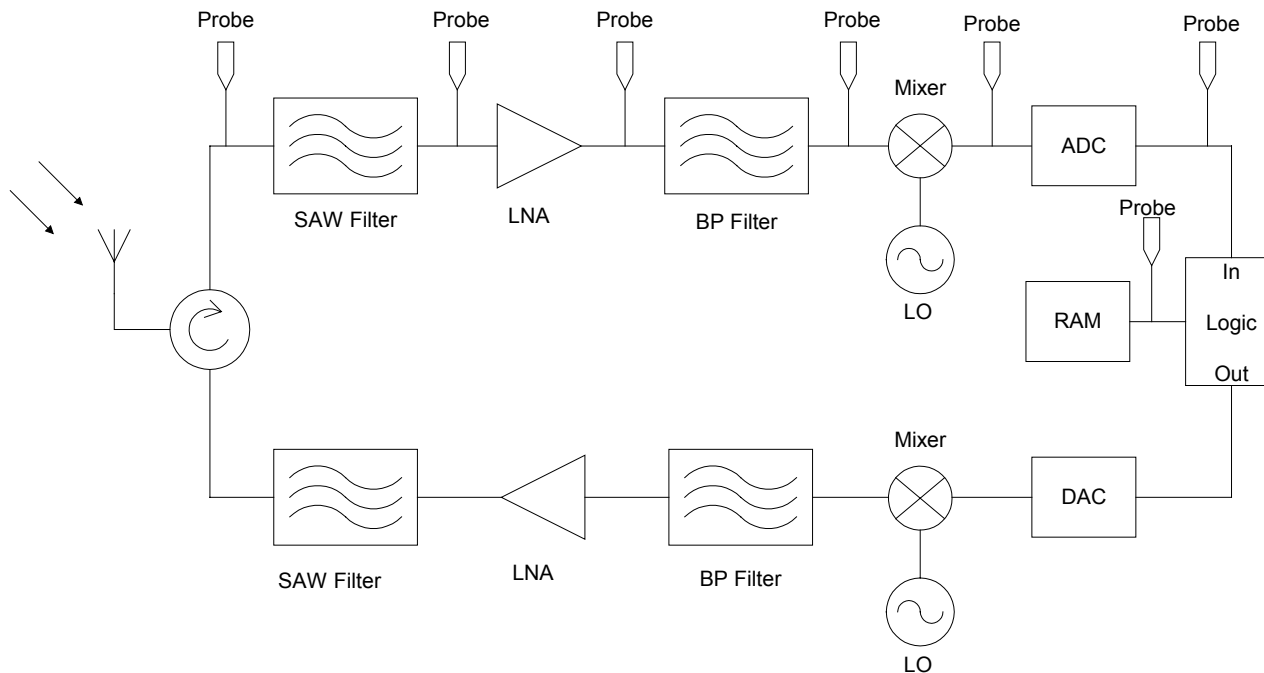


## Outline and Motivation

- *Out-of-band frequency response in communications circuits*
  - *Effect of parasitic elements on network performance*
  - *Degradation in filter rejection ratios*
  - *EMP propagation on signal path*
  - *Need for wideband circuit characterization and verification throughout the communications network (RF and IF path, mixer, A/D, power vias, etc.)*
- *Experimental study of device upset using direct RF injection*
  - *Identify RF characteristics that produce bit errors, latch-up*
  - *What are the EMP effects at the device level?*
  - *Modulation and nonlinear circuit response*
- *Directions to pursue*
  - *Experiment*
  - *Modeling*



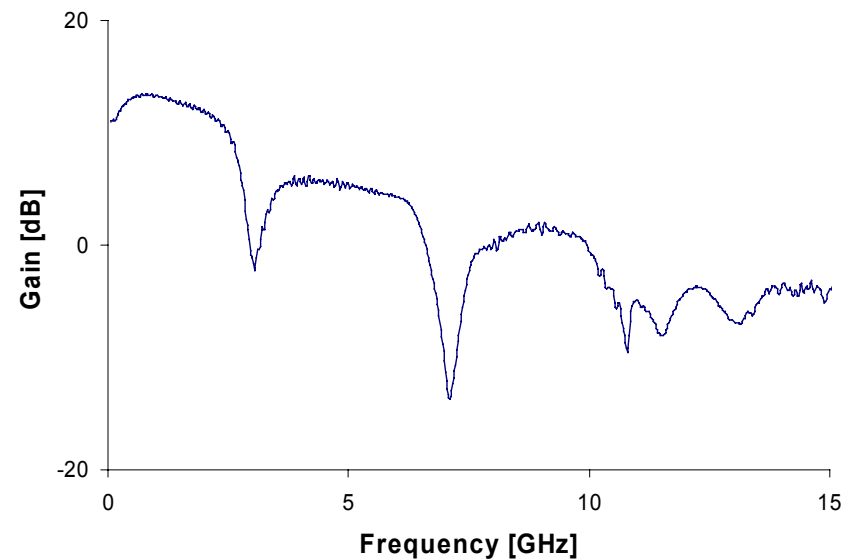
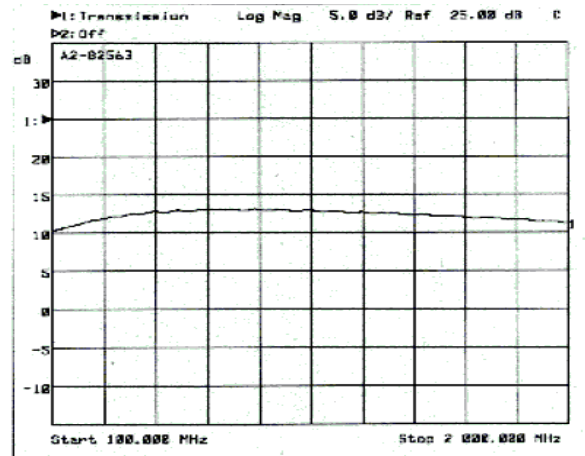
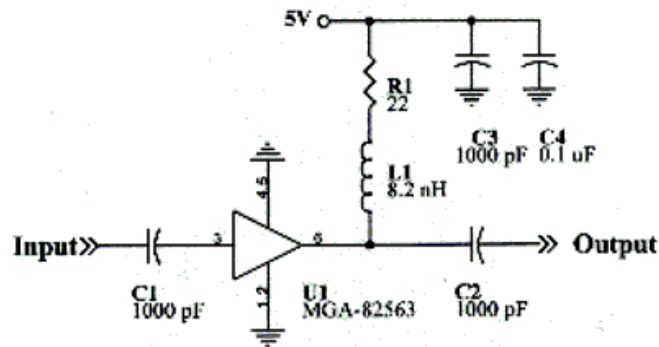
## Schematic of a “loop-back” test circuit for investigating RF effects in digital communications systems and components



Find possible RF entry points, pathways and circuit effects that may upset the system or corrupt data.

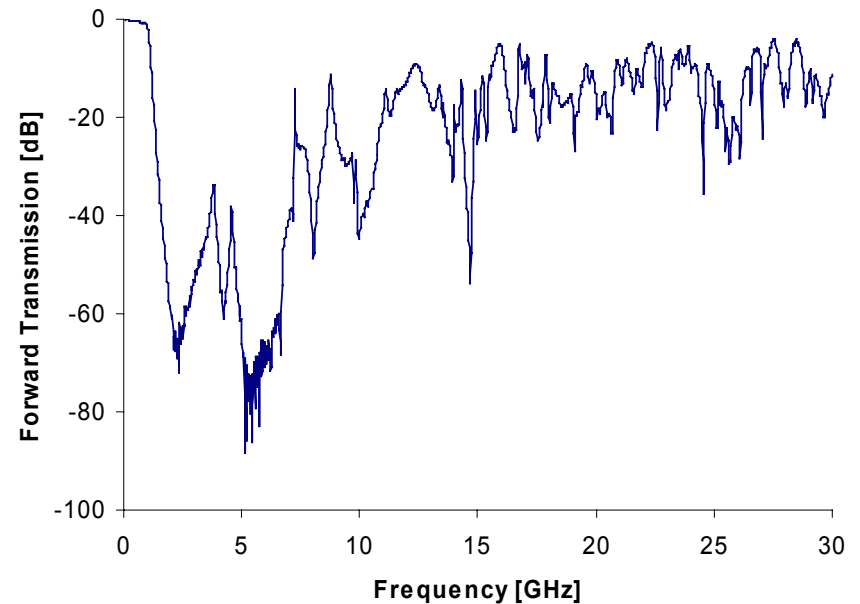
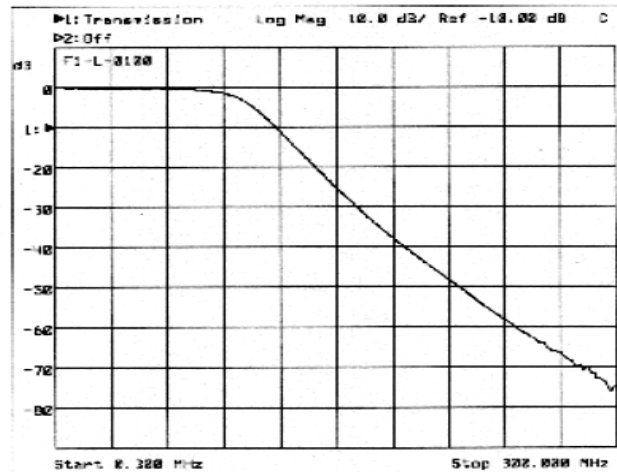
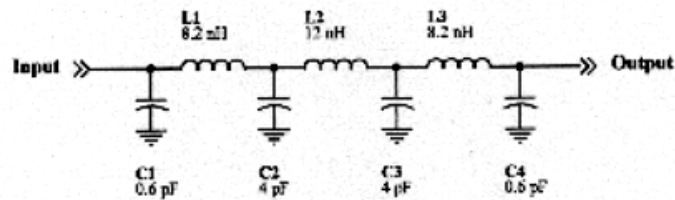


## Example: 2 GHz RF LNA



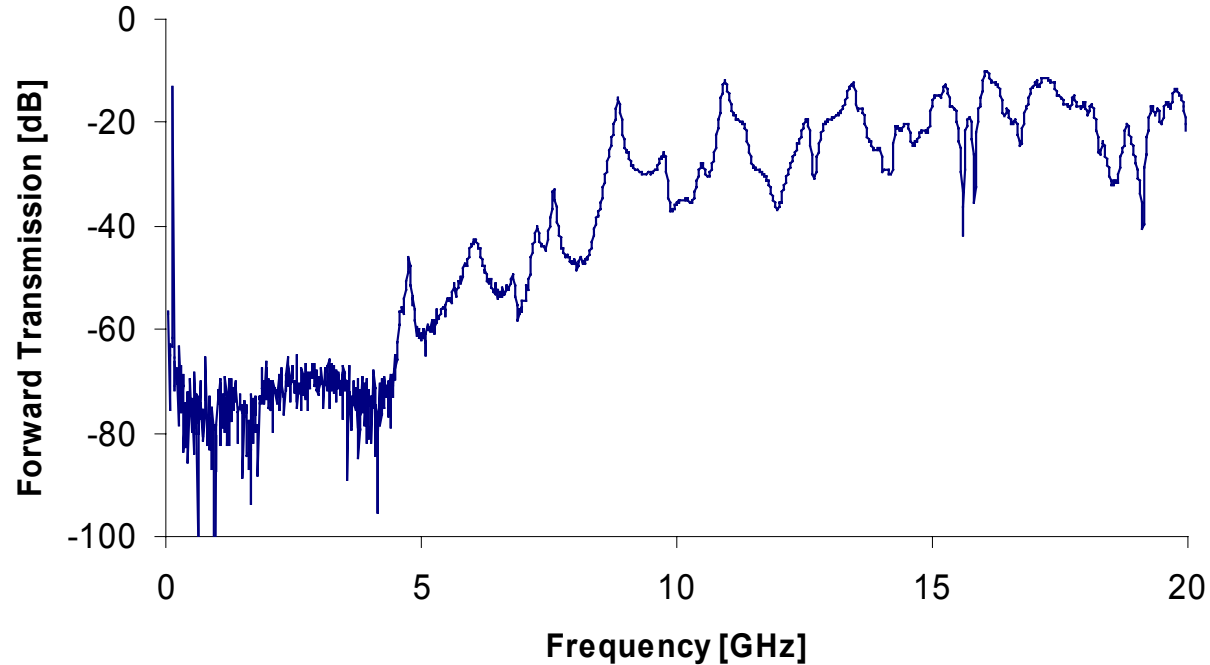


## Example: 1 GHz low pass filter



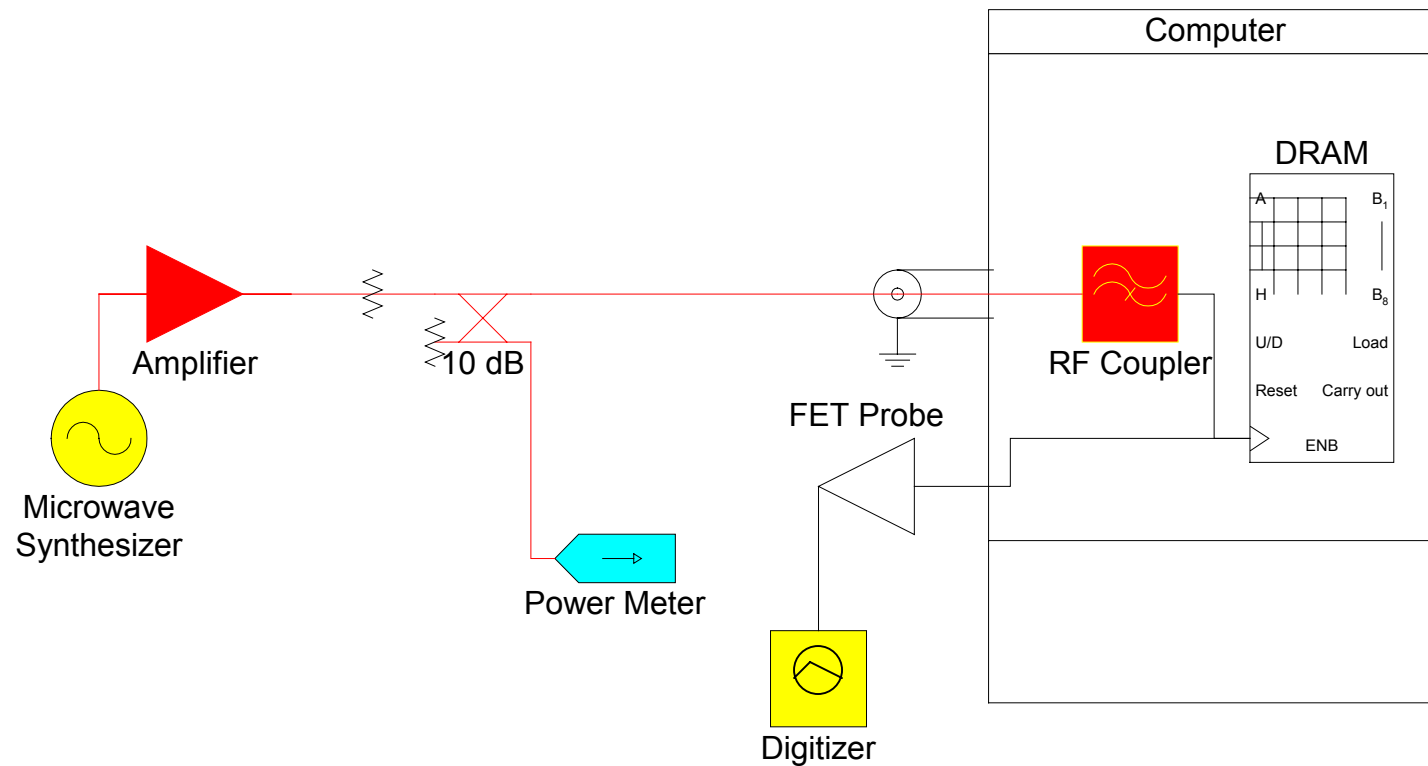


## 140 MHz IF surface acoustic wave (SAW) filter



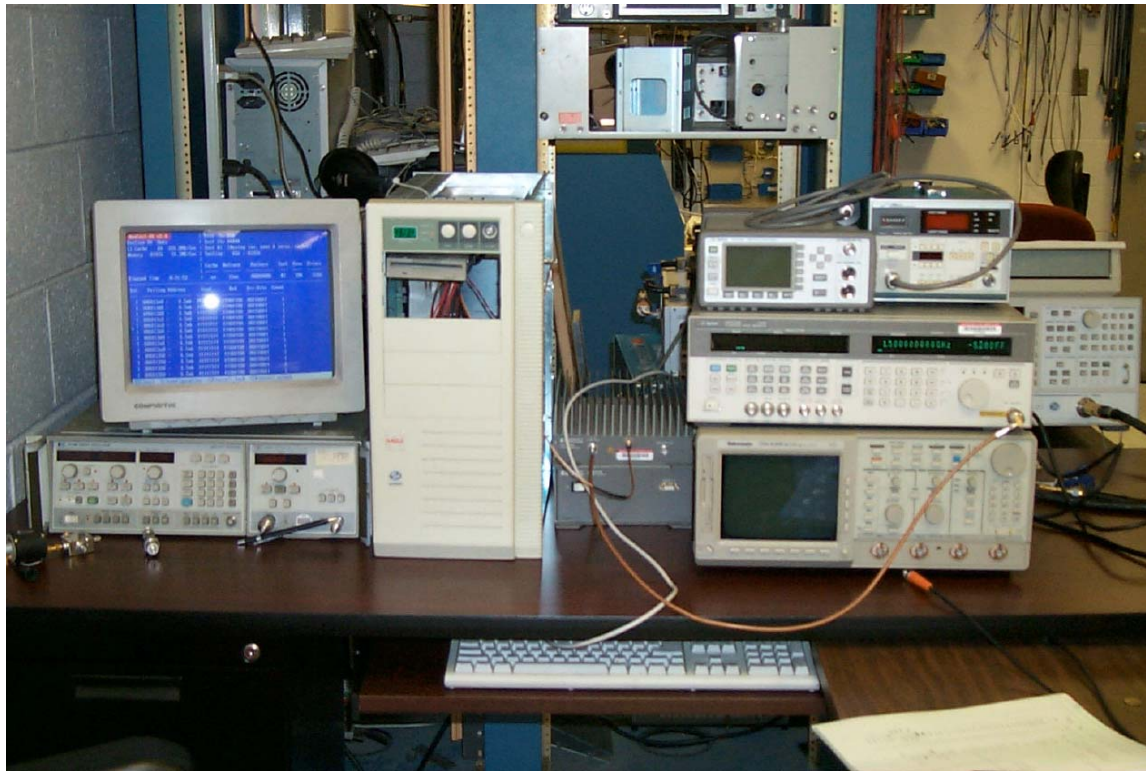


## Schematic of direct injection experiment

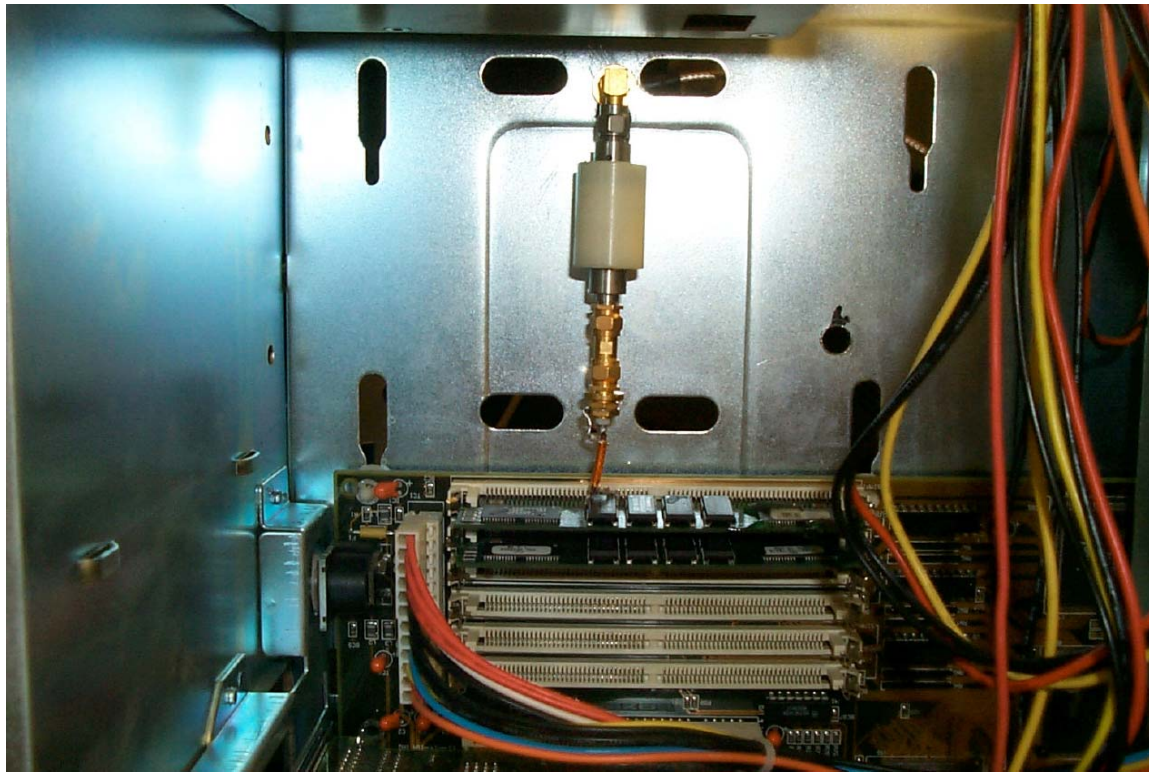




## Direct injection test facility



## View of injection coupler and memory modules inside computer



## Memory checking code displaying bit errors

ntest-86 v2.4  
ntium 90 .0mhz  
Cache 8k 299.9MB/Sec  
Memory 8192k 19.1MB/Sec

Pass100  
Test10  
Test #1 [Moving inv, ones & zeros, cached]  
Testing: 0 - 640k Relocated

Elapsed Time 0:05:09

Cache	Refresh	Pattern	Test	Pass	Errors
on	15ms	ffffffff	#1	10	264

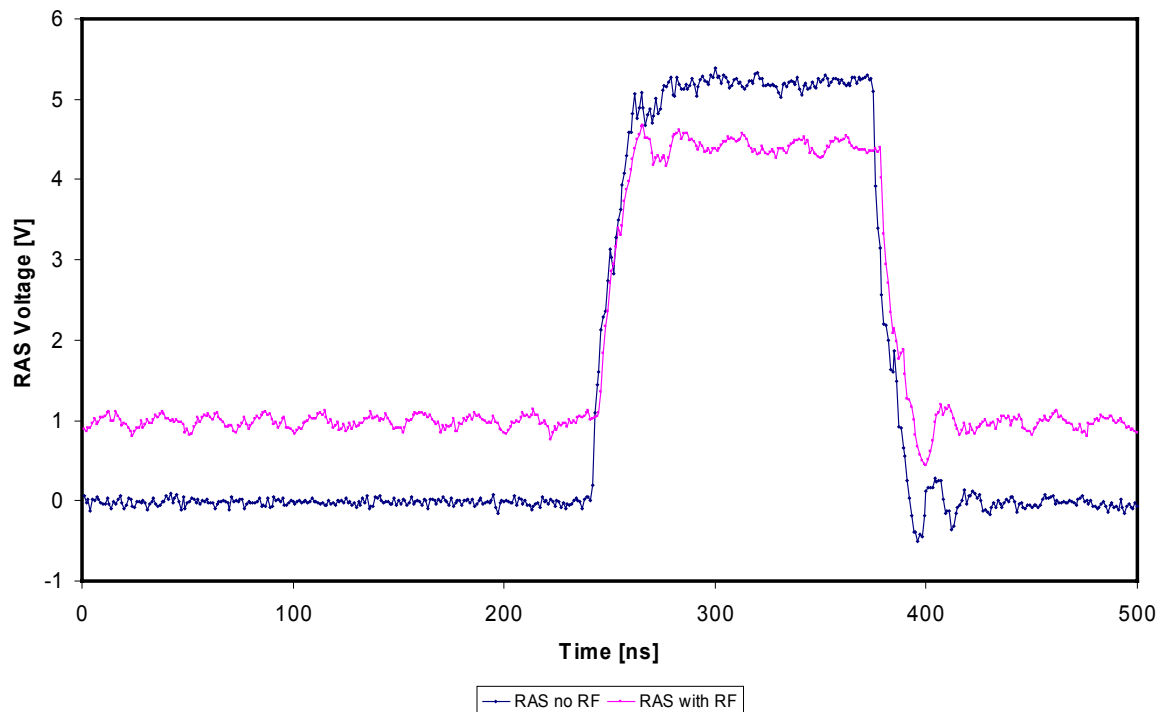
st	Failing Address	Good	Bad	Err-Bits	Count
1	00077860 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077858 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077850 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077848 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077840 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077838 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077830 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077828 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077820 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077818 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077810 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077808 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1
1	00077800 - 0.4mb	ffffffff	ff00ff00	00ff00ff	1

exit (c)configuration (CR)scroll lock (CR)scroll unlock



## RAS logic waveform with and without RF injection

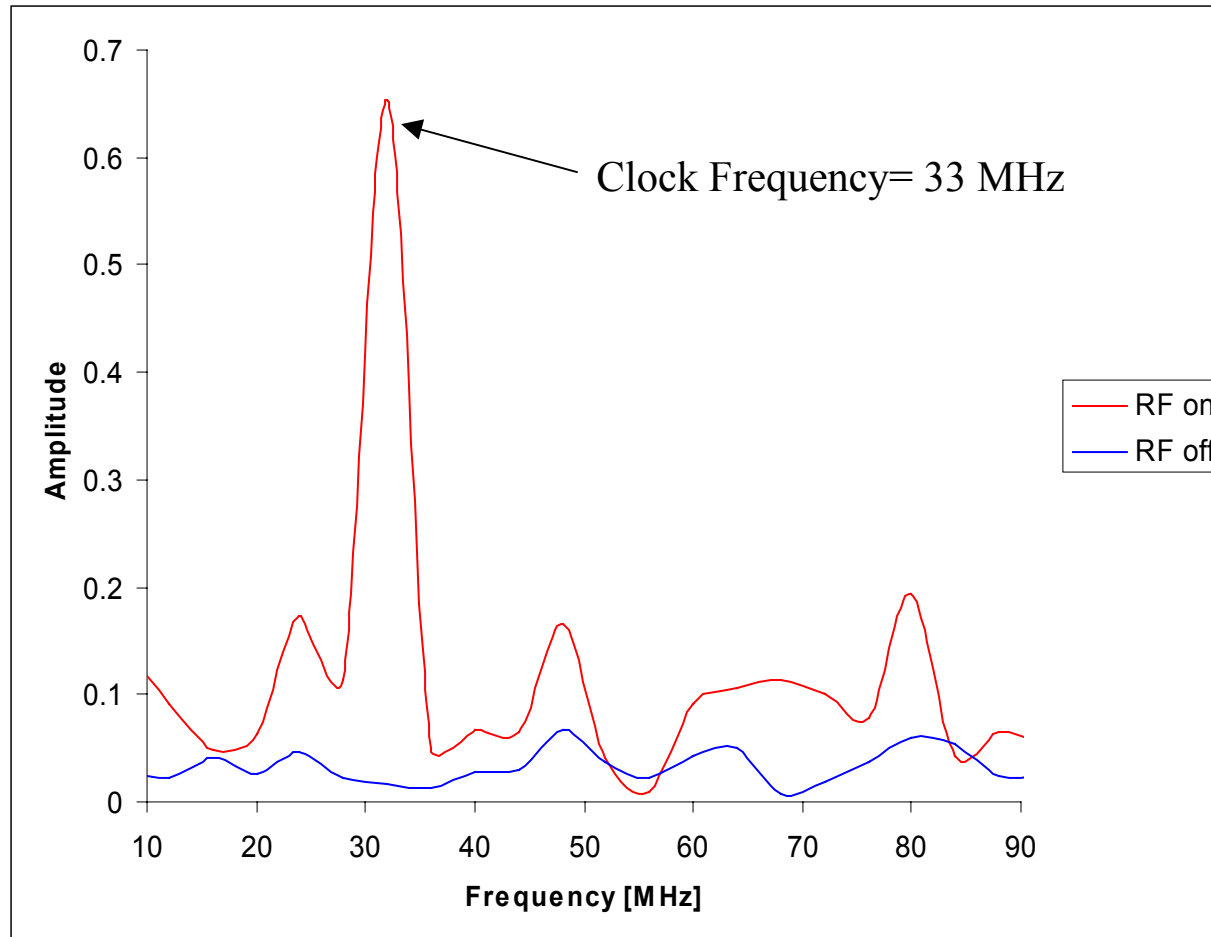
Row Addressing Pin on DRAM Panasonic 424100  
RF applied (1.965 GHz at 26 dBm)



- Device no longer latches to Vdd and Vss
- RF changes operating bias point
- Susceptibility may involve synergistic effects where RF increases likelihood of interference from internal signals.



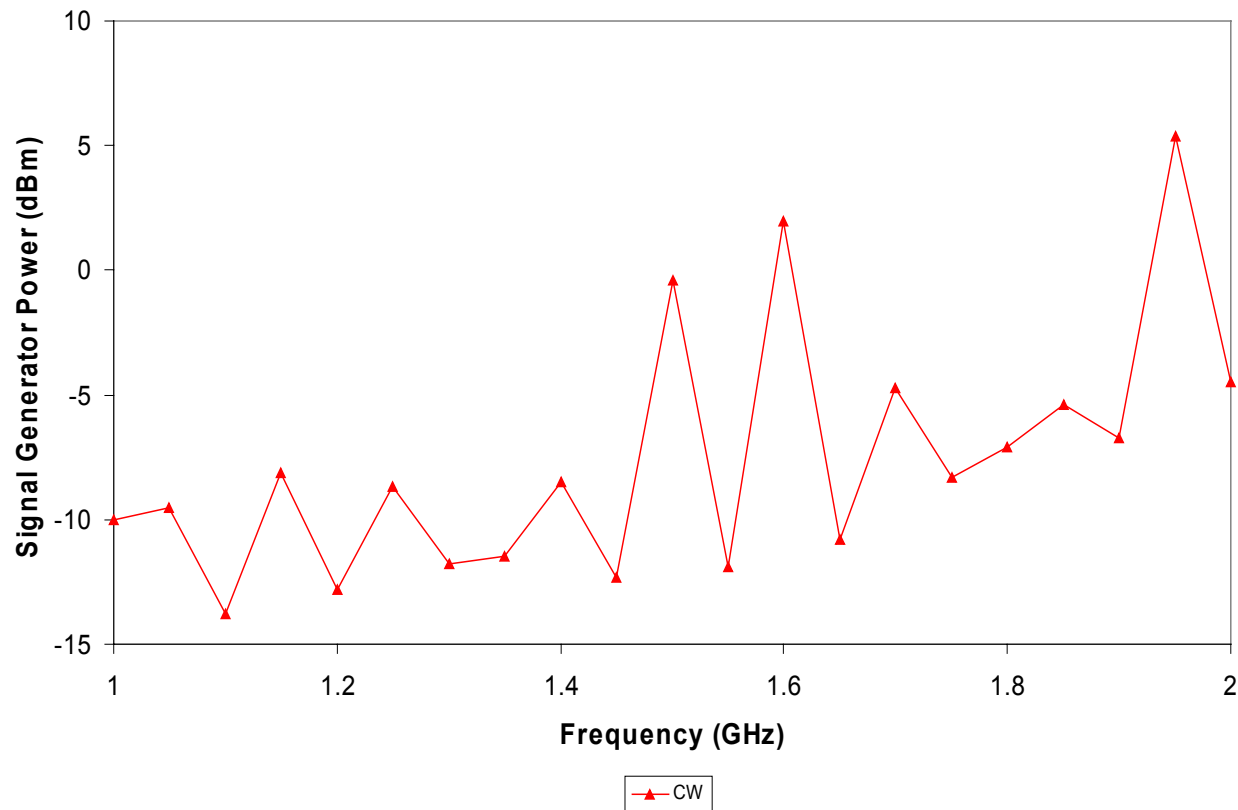
## Frequency spectrum of RAS waveform





## Results with CW injection

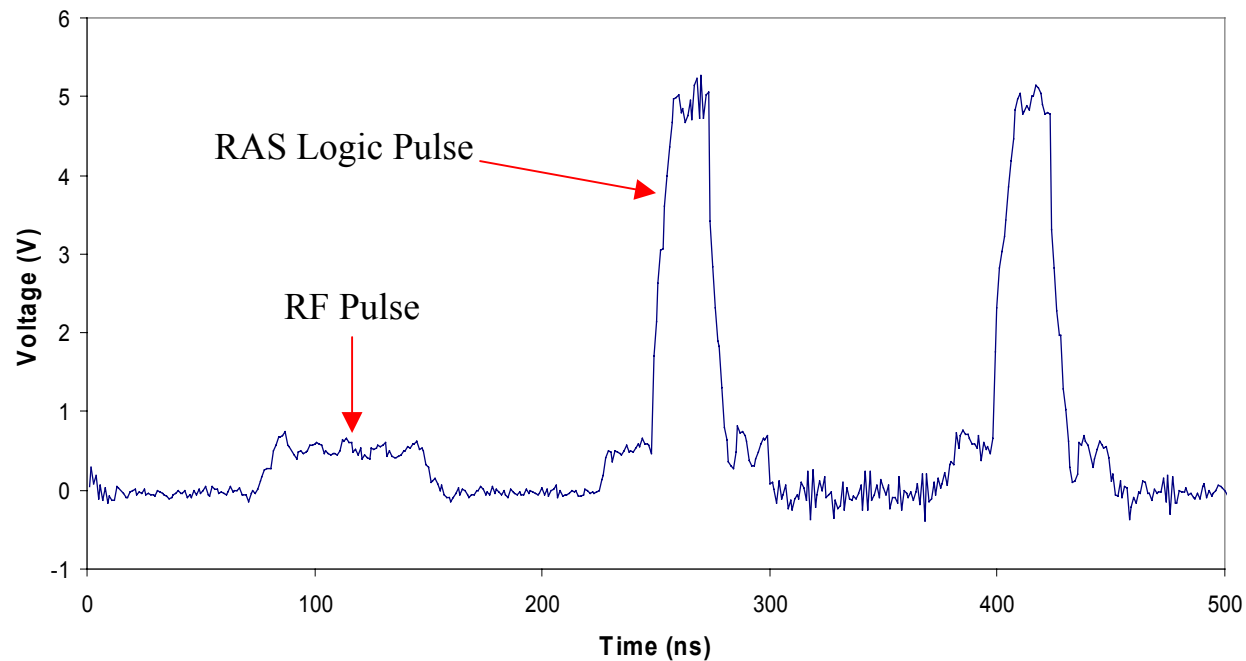
Threshold Power to cause Bit Error at RAS pin  
Signal Generator Power





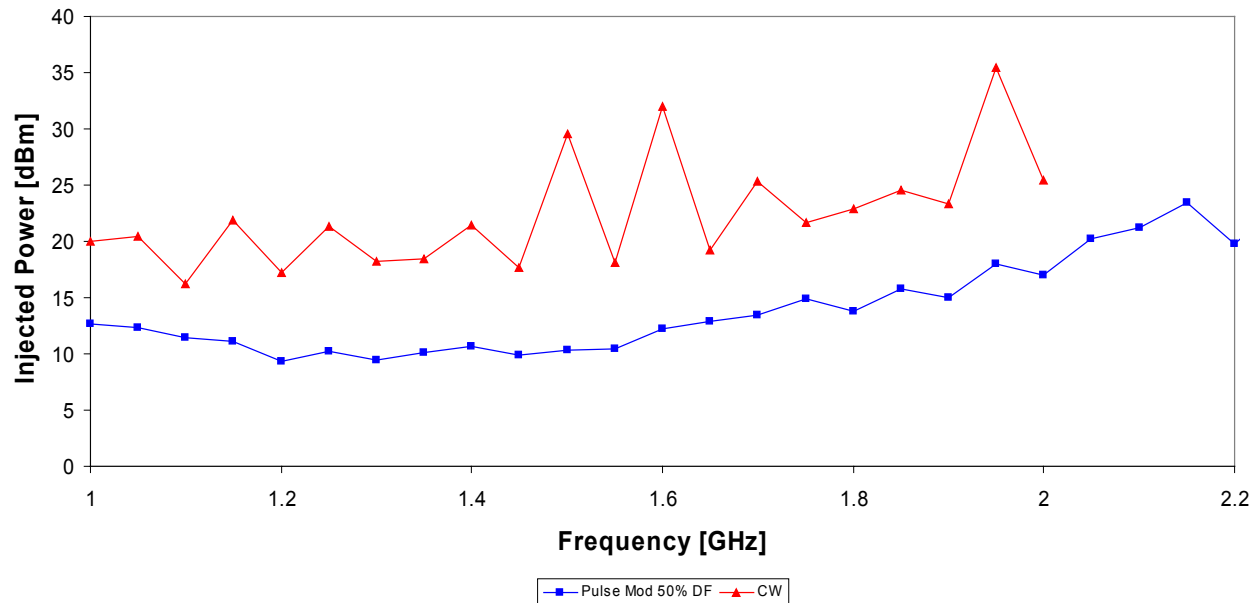
## RAS Voltage vs. time with Pulsed RF Injection ( $f \sim 2$ GHz)

RAS Pin with injected RF before interrupt  
1.965 GHz (PW=150 ns, PRI=300 ns, Pin=29.4 dBm)



# Comparison of results with CW and pulsed injection

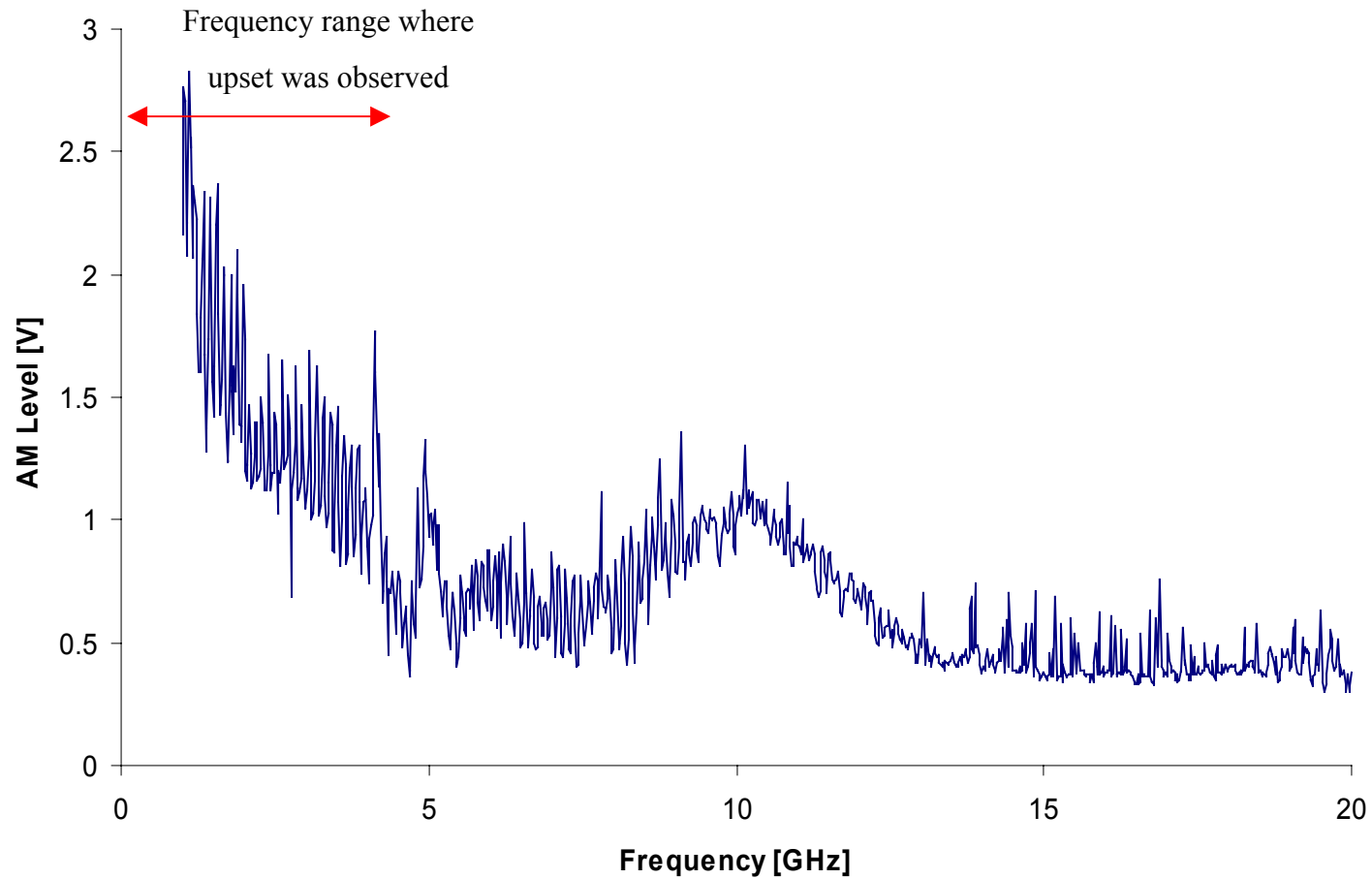
Threshold Power to cause Bit Error at RAS pin





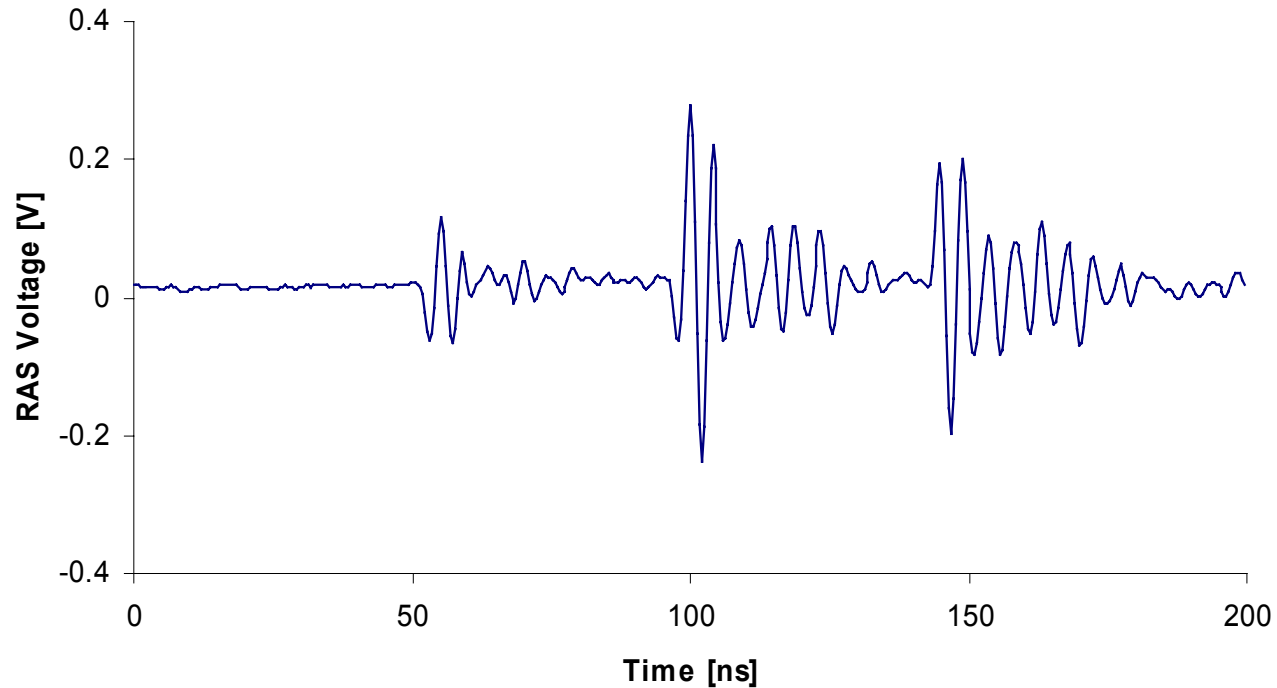


## Amplitude of demodulated RF signal on RAS vs. frequency





## Transients induced on RAS by RF pulses at frequencies up to 20 GHz



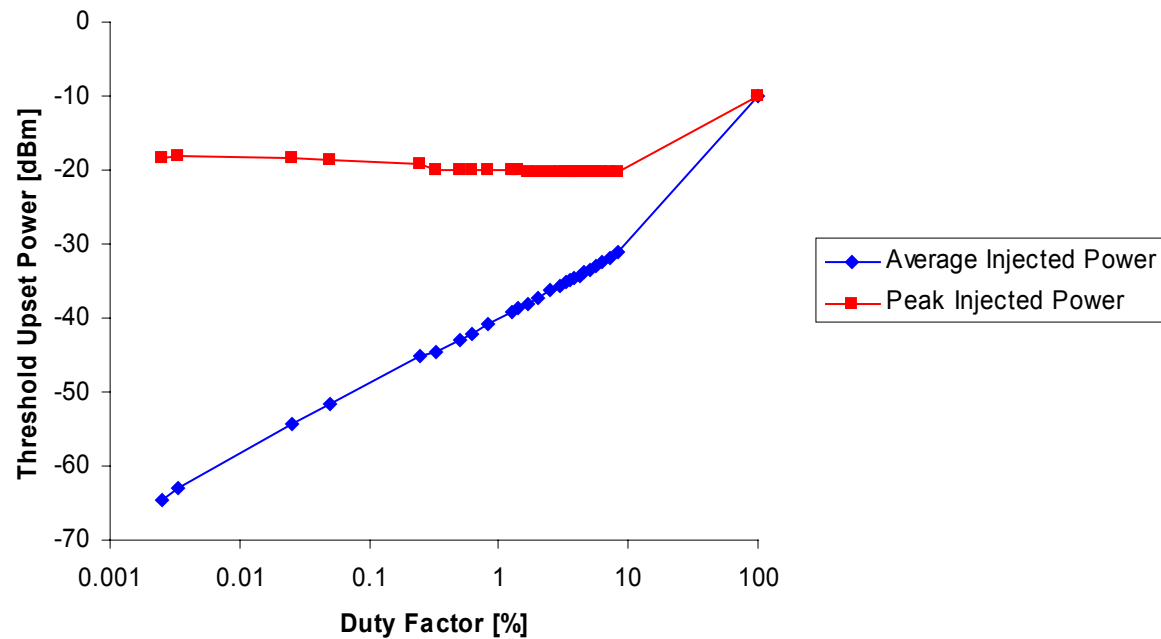


## What mechanisms may be responsible for the observed effects?

- Thermal: localized RF energy deposition and rapid heating of active MOS regions
- Hot-carriers
- Nonlinear circuit elements
  - MOS diodes acting as RF detectors
  - Demodulation of RF by parametric capacitances

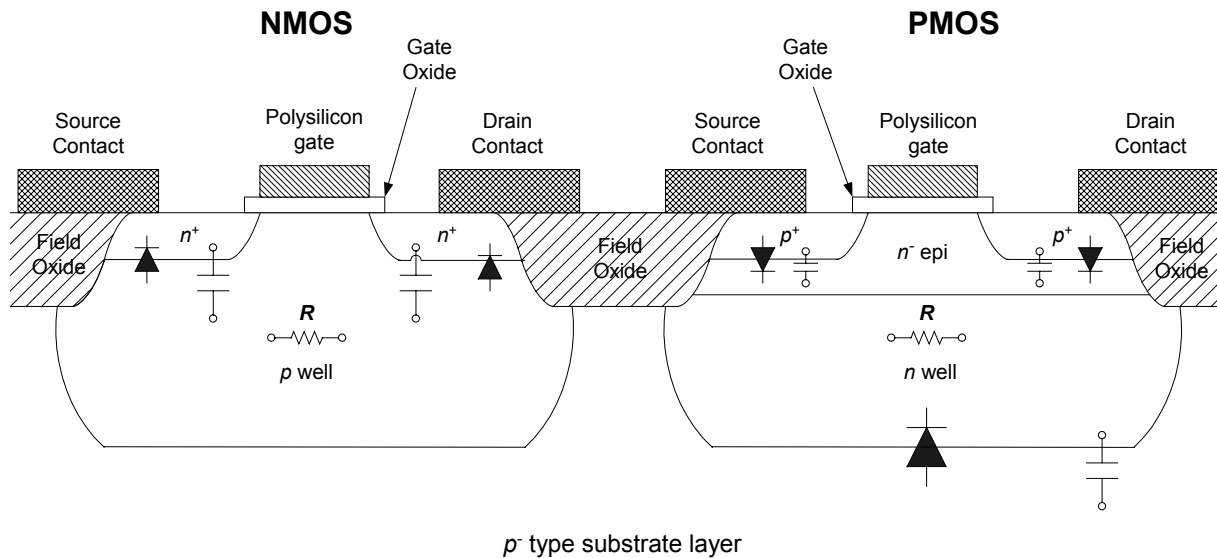


## Upset threshold power vs. duty factor



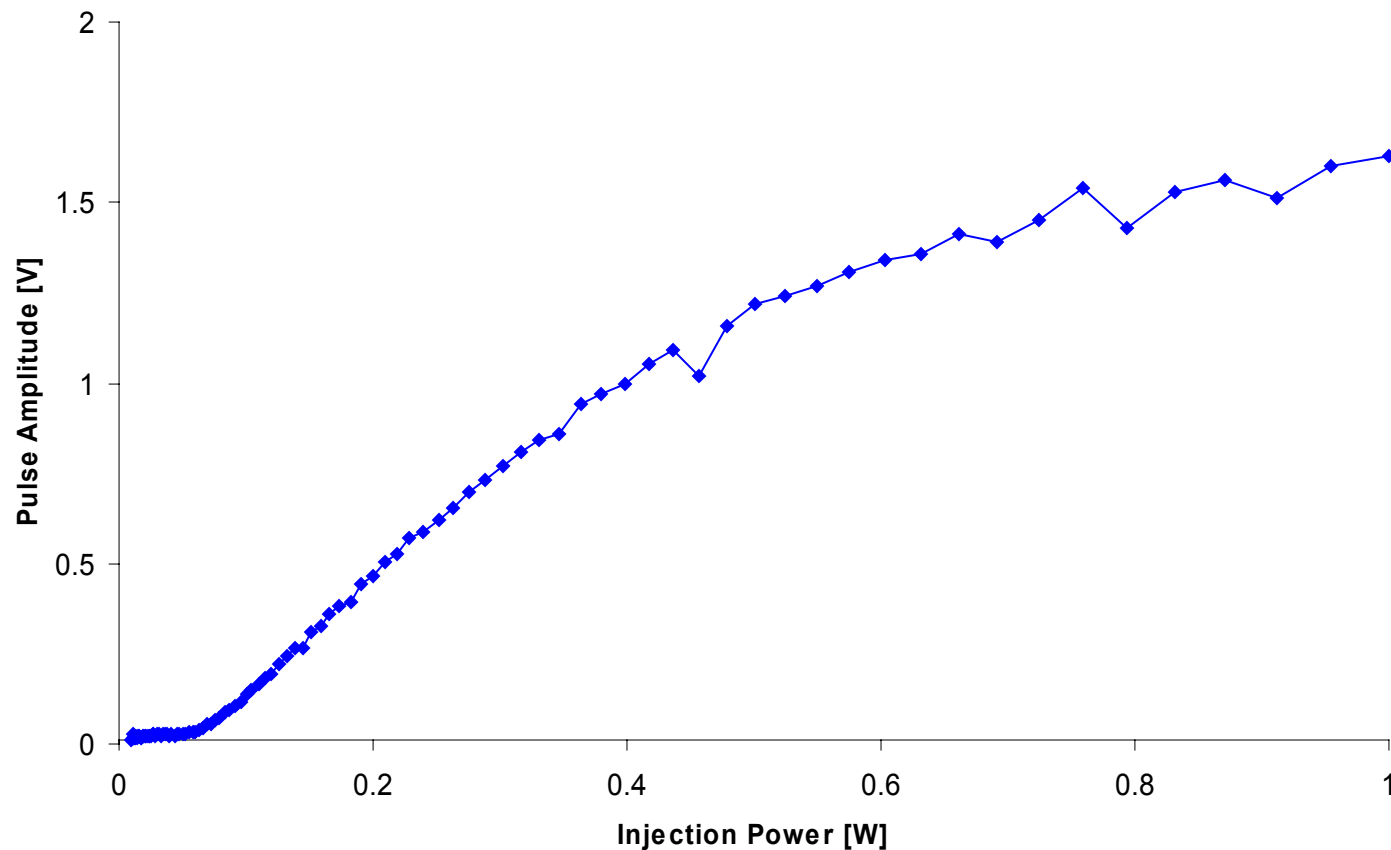
Not a thermal effect

# Physical Cross-section of CMOS showing equivalent circuit elements with nonlinear electrical characteristics



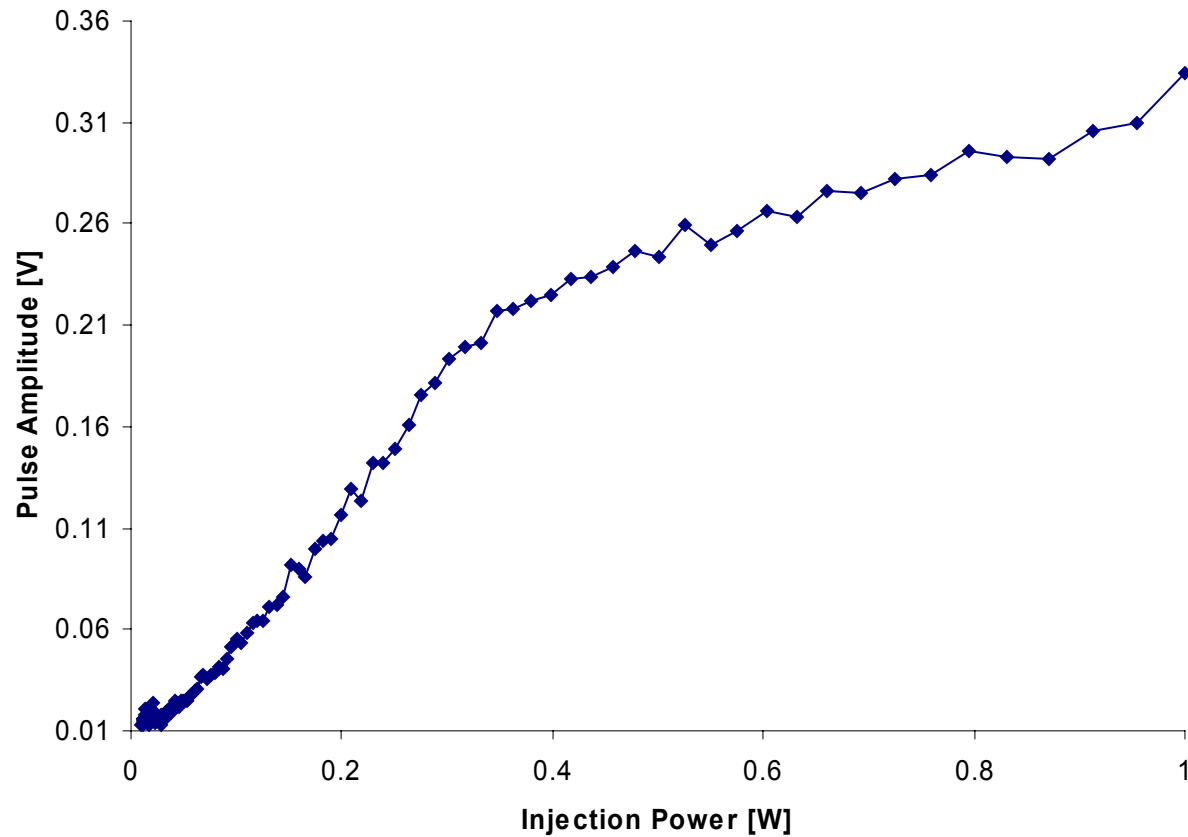


## Drive characteristic of demodulated 4.12 GHz pulse





## Drive characteristic of 6.0 GHz transient pulse





## Conclusions

- High frequency response of communications circuits must be considered when analyzing susceptibility to determine probable entry and propagation paths for EMP.
- The RF shifts the operating bias with respect to  $V_{dd}$  and  $V_{ss}$  into a nonlinear amplification regime, which could lead to instability, oscillation and chaotic behavior.
- RF pulses are demodulated by nonlinear MOS elements. The envelop voltage constitutes the interrupting signal.
- EMP rise time is a key parameter for inducing interrupt signals over wide bandwidths.





## Future Work

- The experimental results give basis for modeling high frequency effects in devices
- Continue to characterize device-level upset mechanisms and seek to develop generalized formalisms
- Study the effects of complex modulation
- Look at smaller, faster structures (CPU, RDRAM, DDR, etc.) and investigate how scaling laws may be applied
- Investigated RF effects in mixed signal systems (A/D, demodulators, etc.)